# Pneumatic Active/Passive Devices for Wearable Robots

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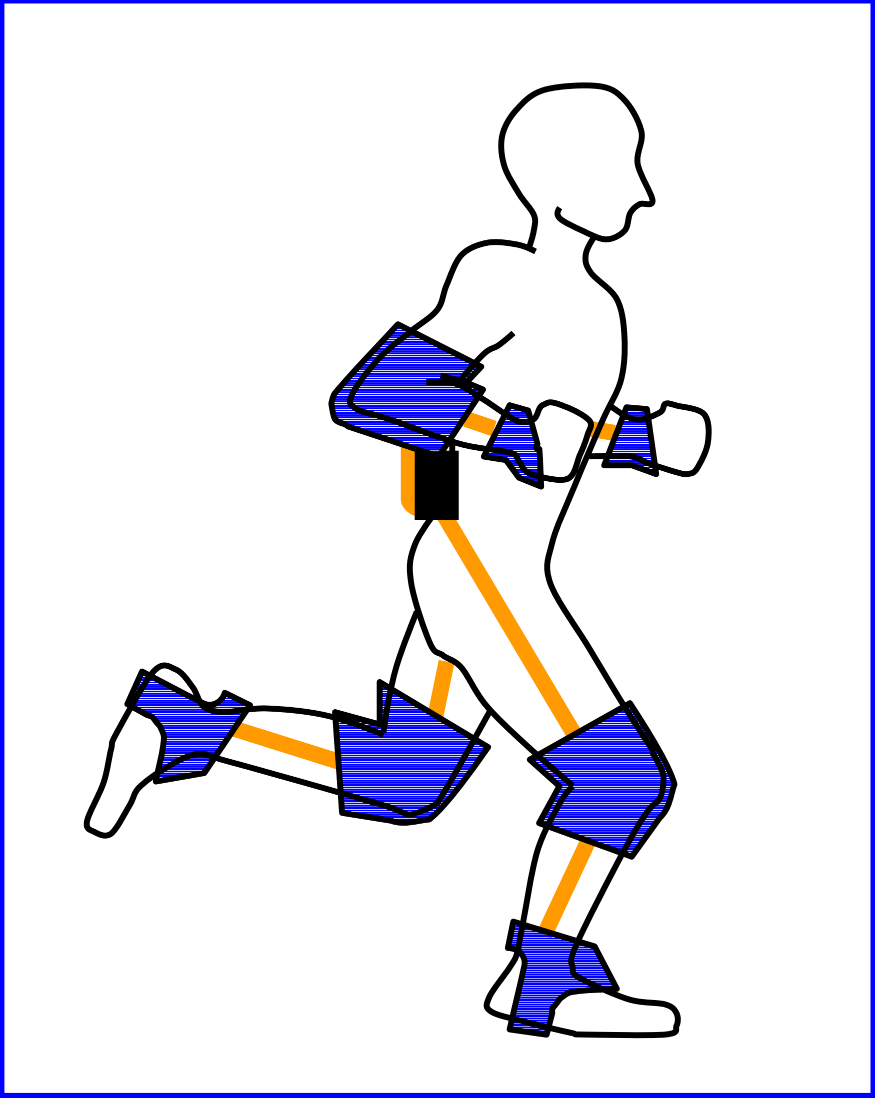
# Soft Mechanical Suits



Wearable
mechanical system
to support human action

Sports exercise
Rehabilitation

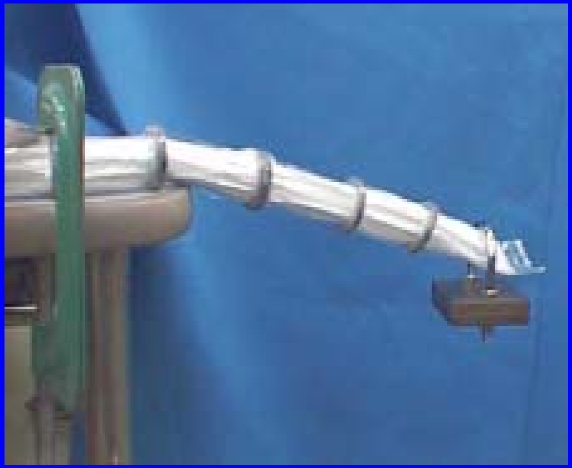
# Issues to be tackled

- Soft and Light-weighted Devices
  - conform to human body
  - actuators/variable impedance devices
- System Integration
  - attaching to human body
  - control

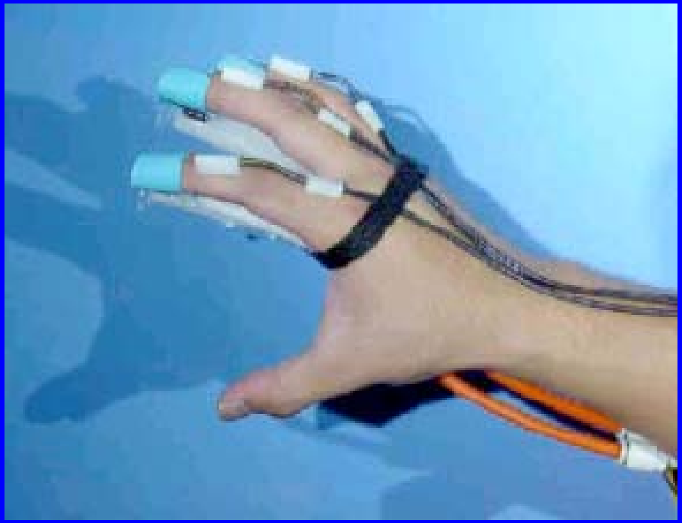
# Soft and Light-weighted Devices

Solution

Pneumatic devices

# System Integration



# Human Motion Support

Force along human motion

Assist

protector
weight assist
energy accumulator

motion assistance
virtual reality
rehabilitation

Passive

No energy

Active

Generate energy

virtual reality
rehabilitation
sports exercise

Load

virtual reality
rehabilitation
sports exercise

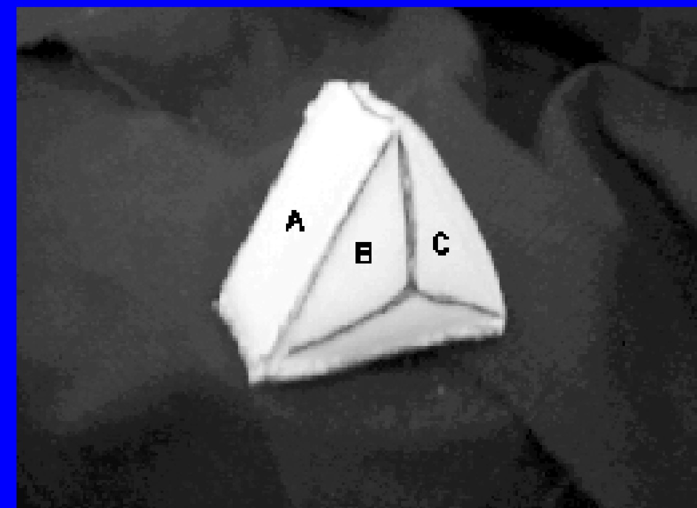
Force against human motion

# Pneumatic Active Devices

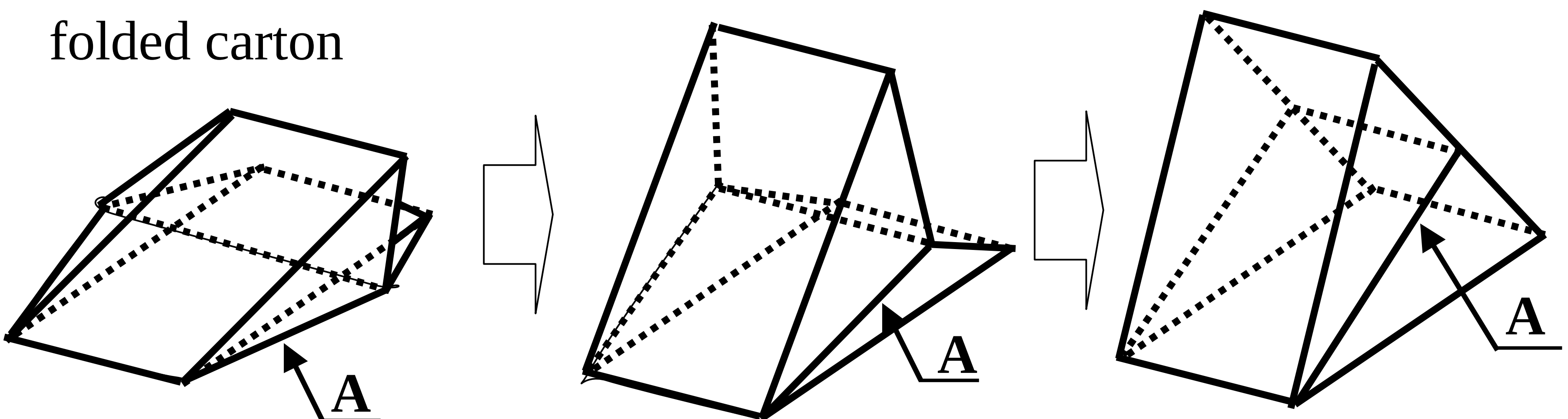

HRA
(Hexahedron Rubber Actuator)

PGA
(Pneumatic Group Actuator)

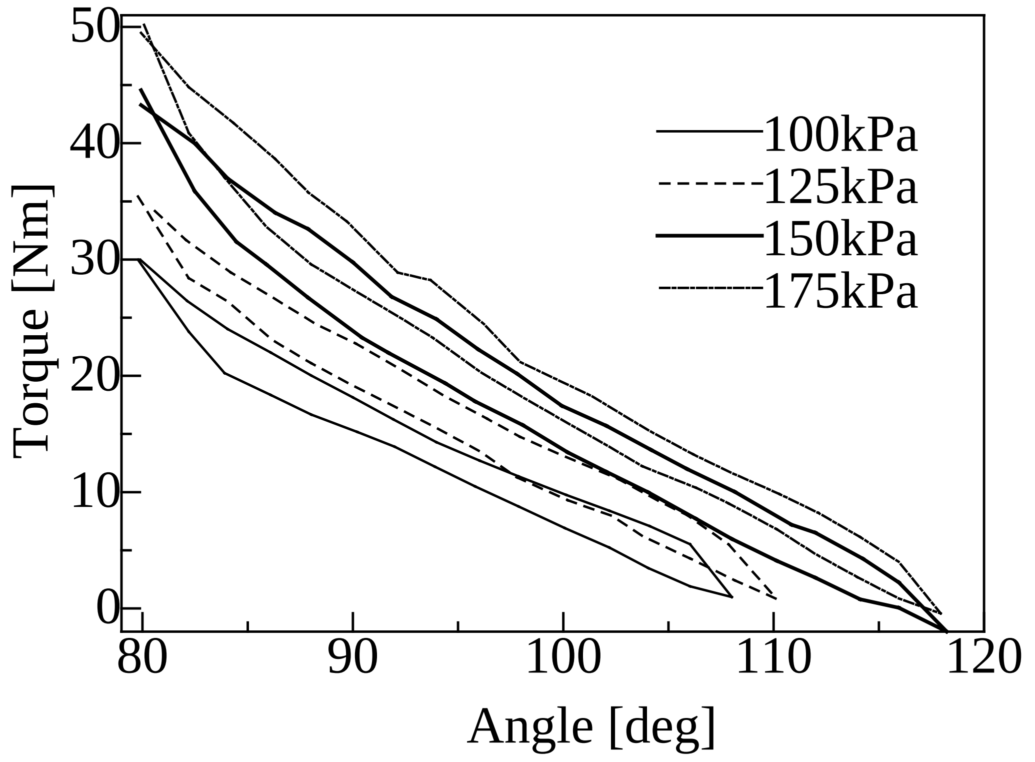
# Hexahedron Rubber Actuator (HRA)



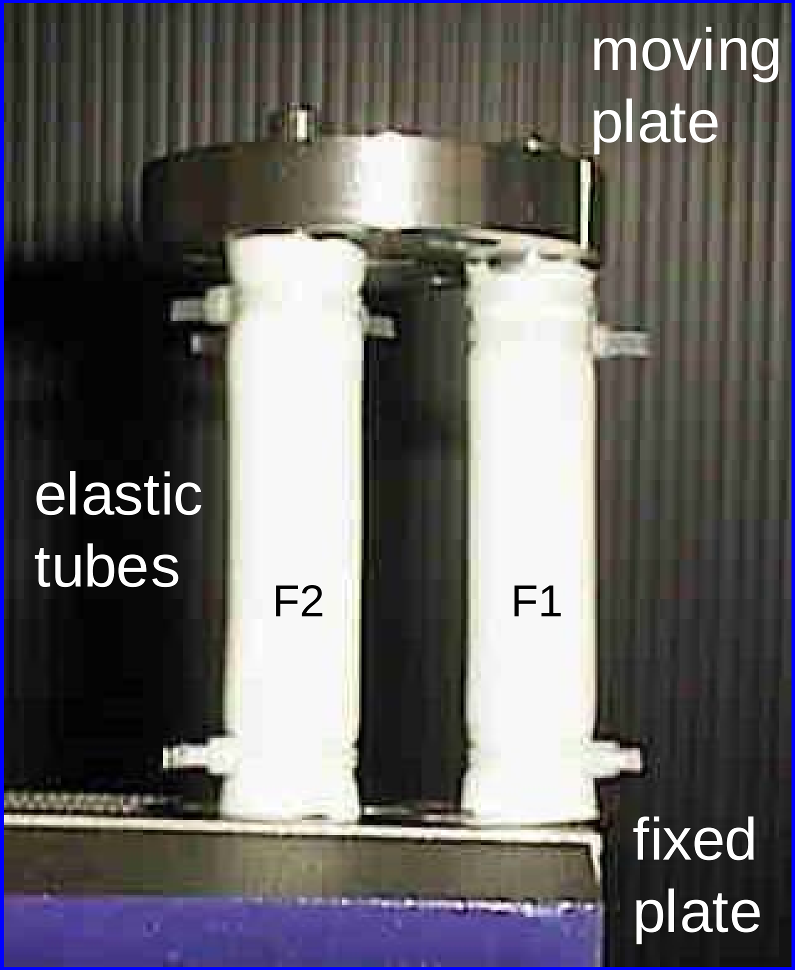

folded carton

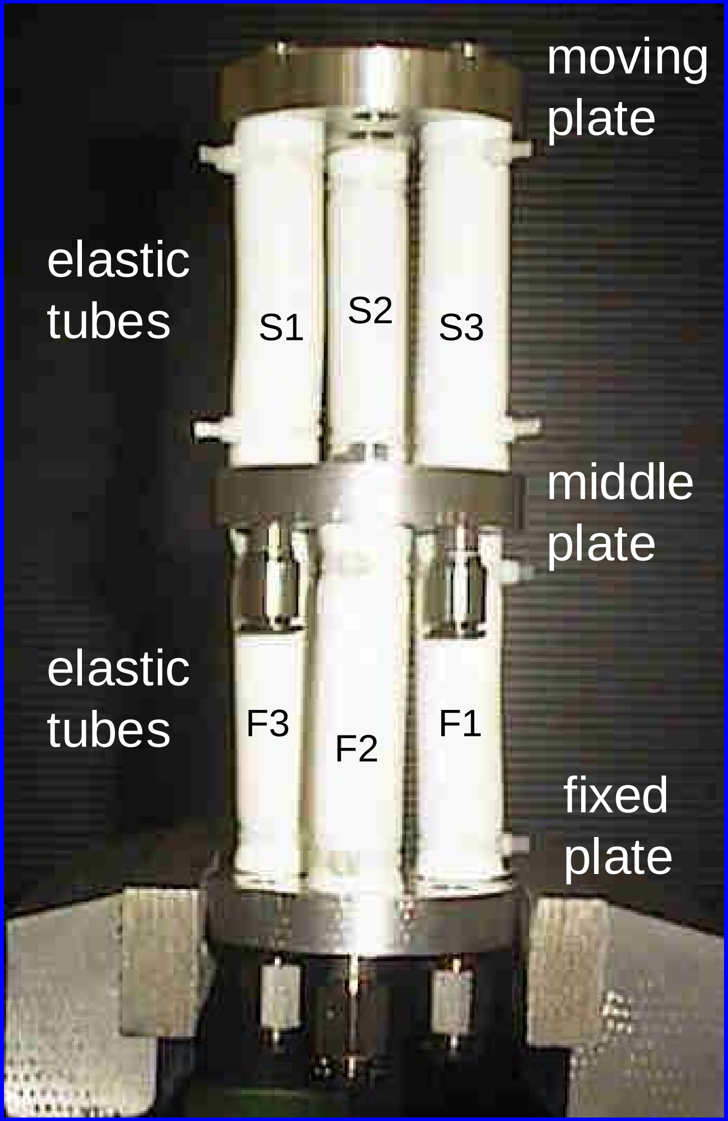


# Property of HRA



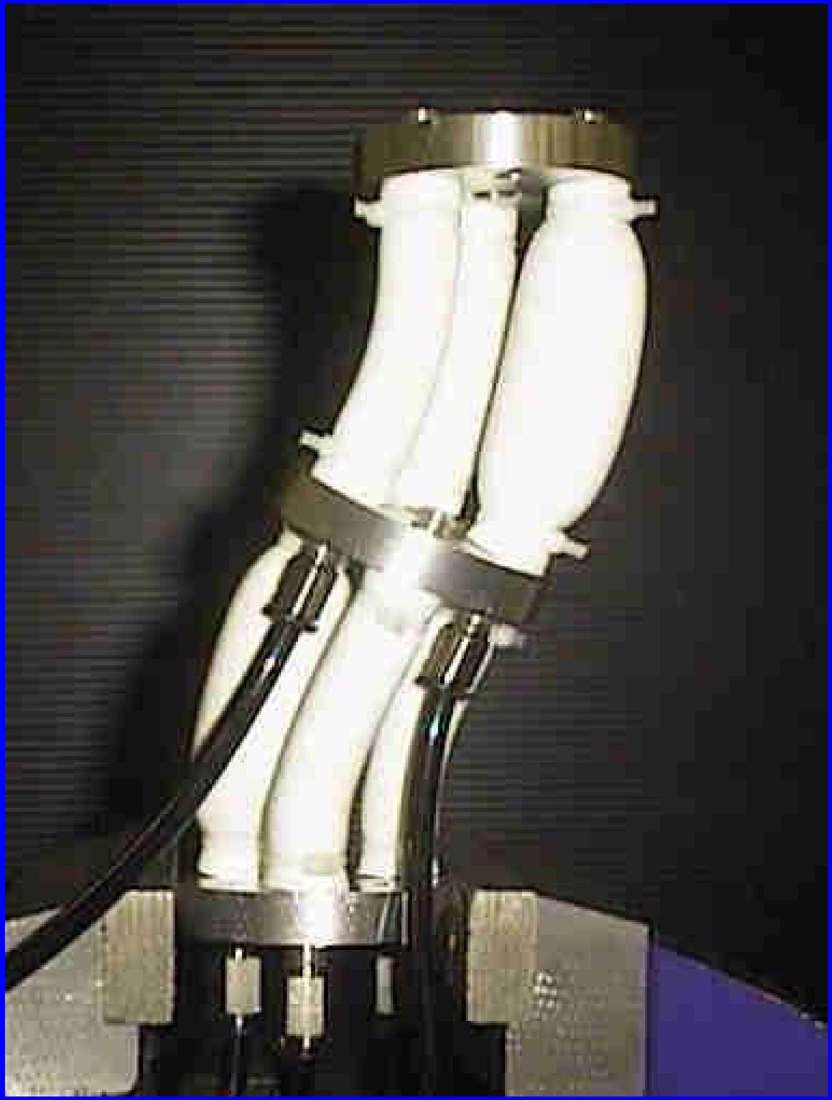
# Pneumatic Group Actuator (PGA)



# Vertical Bend of Double-stage PGA

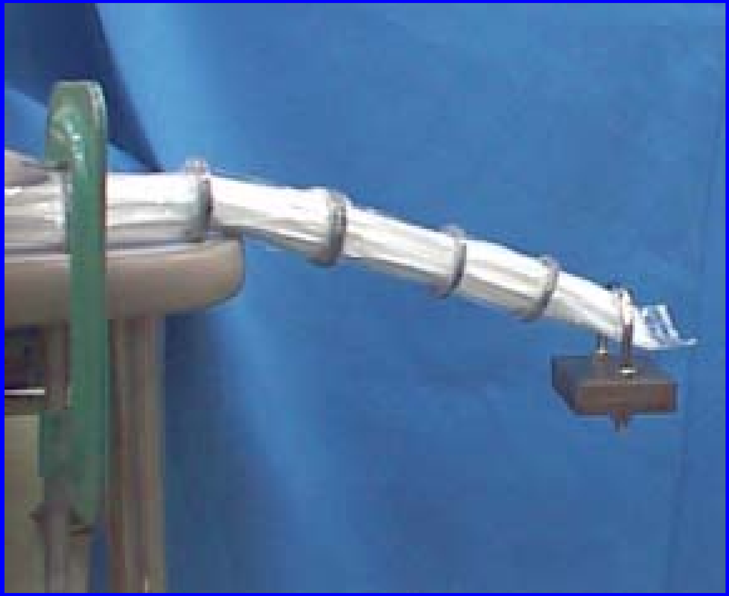
# Motion of Double-stage PGA



# Pneumatic Passive Devices

Variable Bend-rigidity Device

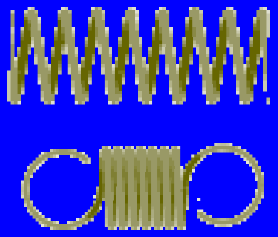
Variable Viscosity Device



Linear Devices

# Traditional passive devices

springs, dampers, brakes



- Constant properties
- Heavy and bulky (not wearable)
- Few freedoms of motion

Goal: Variable-impedance
Wearable devices

Solution: Pneumatic

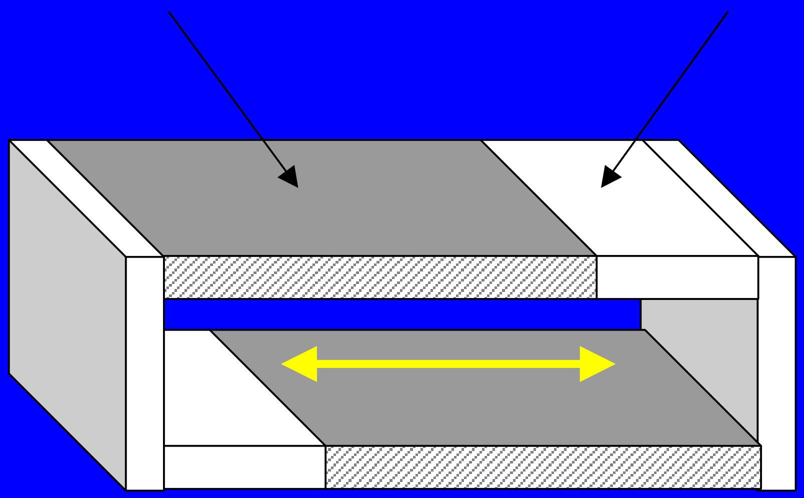
# Qualitative Classification of Passive Devices

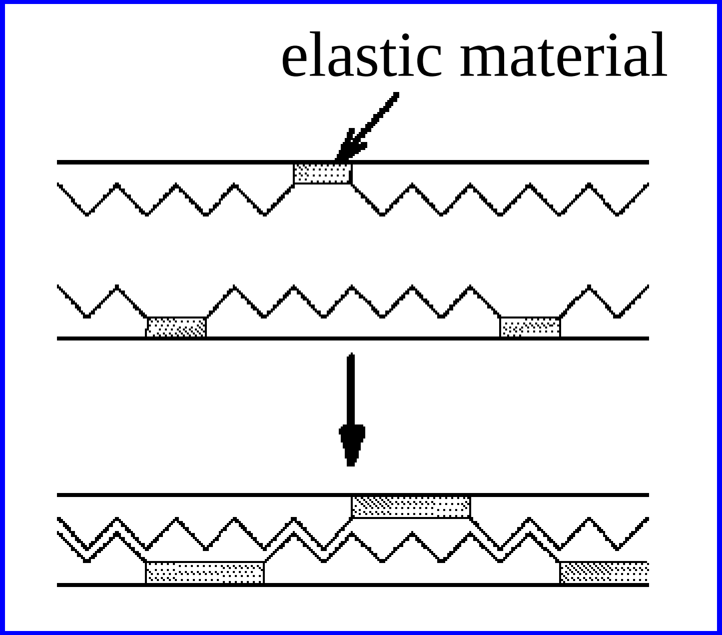
| Type | Expansion / Contraction | Bending | Twisting |
| --- | --- | --- | --- |
| A | V | S or H | S or H |
| B | S or H | V | S or H |
| C | S or H | S or H | V |
| D | V | V | S or H |
| E | S or H | V | V |
| F | V | S or H | V |
| G | V | V | V |

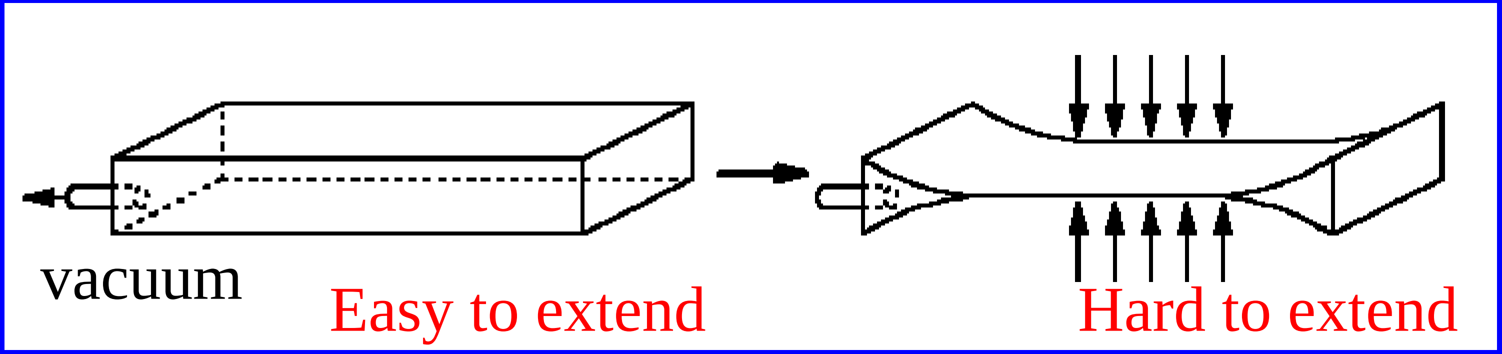
# Variable Extensional-rigidity (VER)

## Type-A

Rigid material Elastic material

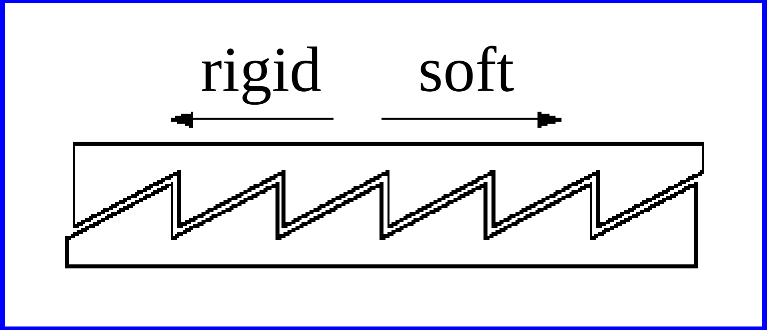




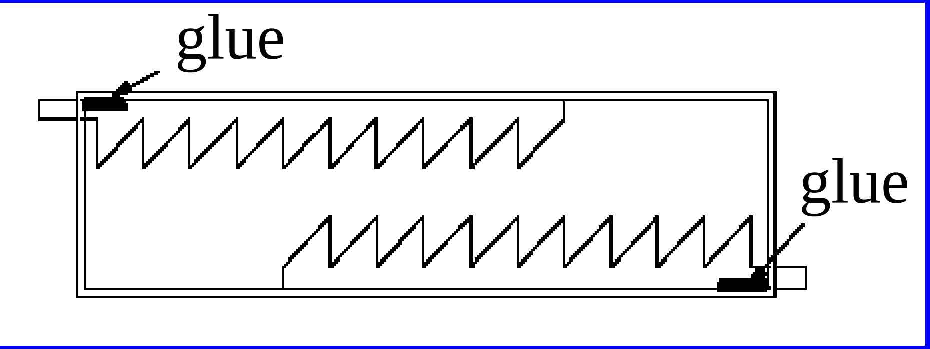



# Prototyping VER device

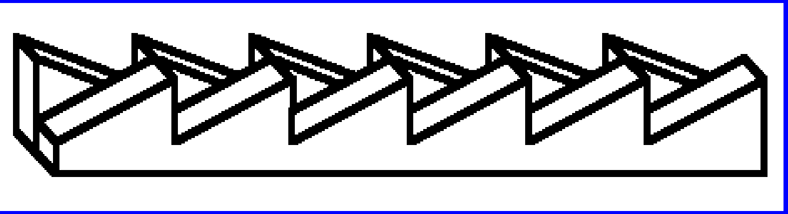
Unidirectional rigidity

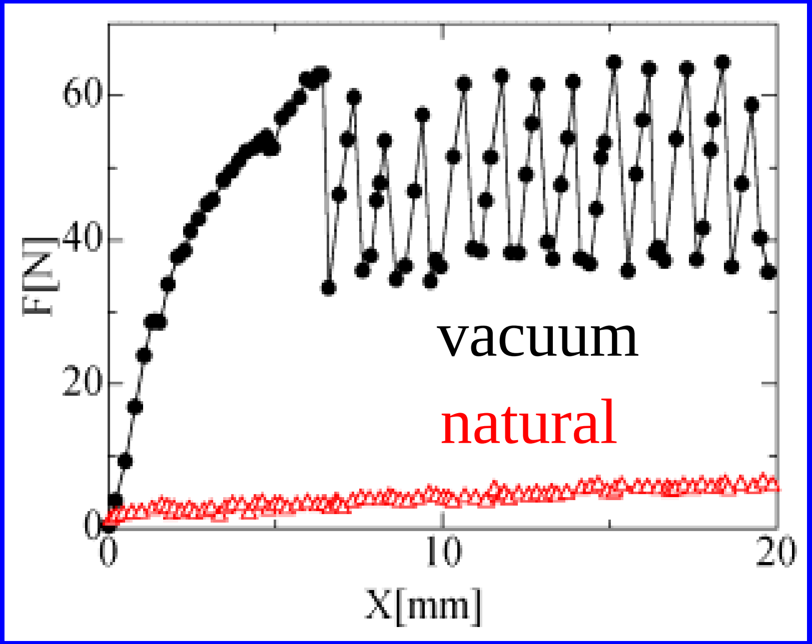



Teeth glued at one end point



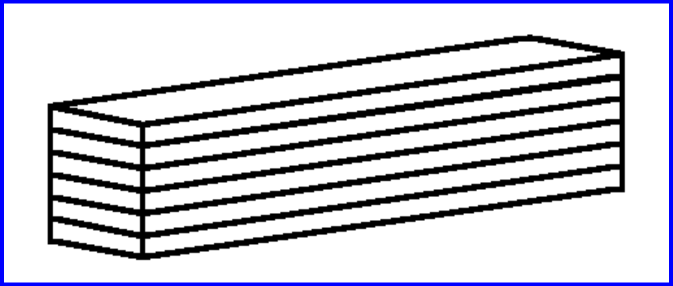

Two rows of teeth for bidirectional rigidity

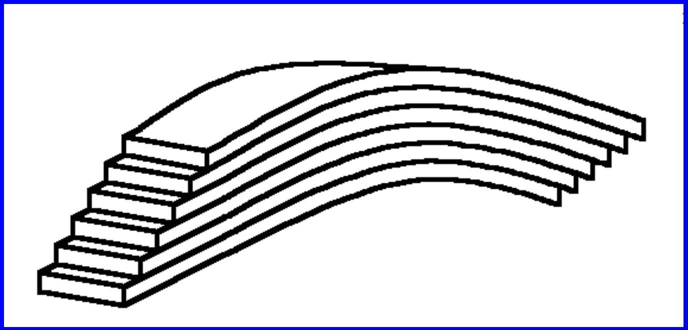




# Variable Bend-rigidity (VBR)

## Type E





Stacked thin films in an envelop
Inside vacuum increases the bend-rigidity

# VBR device - modeling

## Geometrical moment of inertia

$$I_{nor} = \frac{bnh^3}{12}$$

Normal state

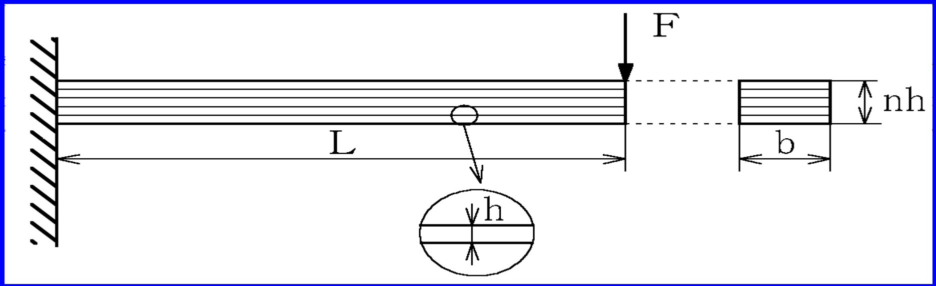
$$I_{vac} = \frac{b(nh)^3}{12}$$

Vacuum state

n number of films

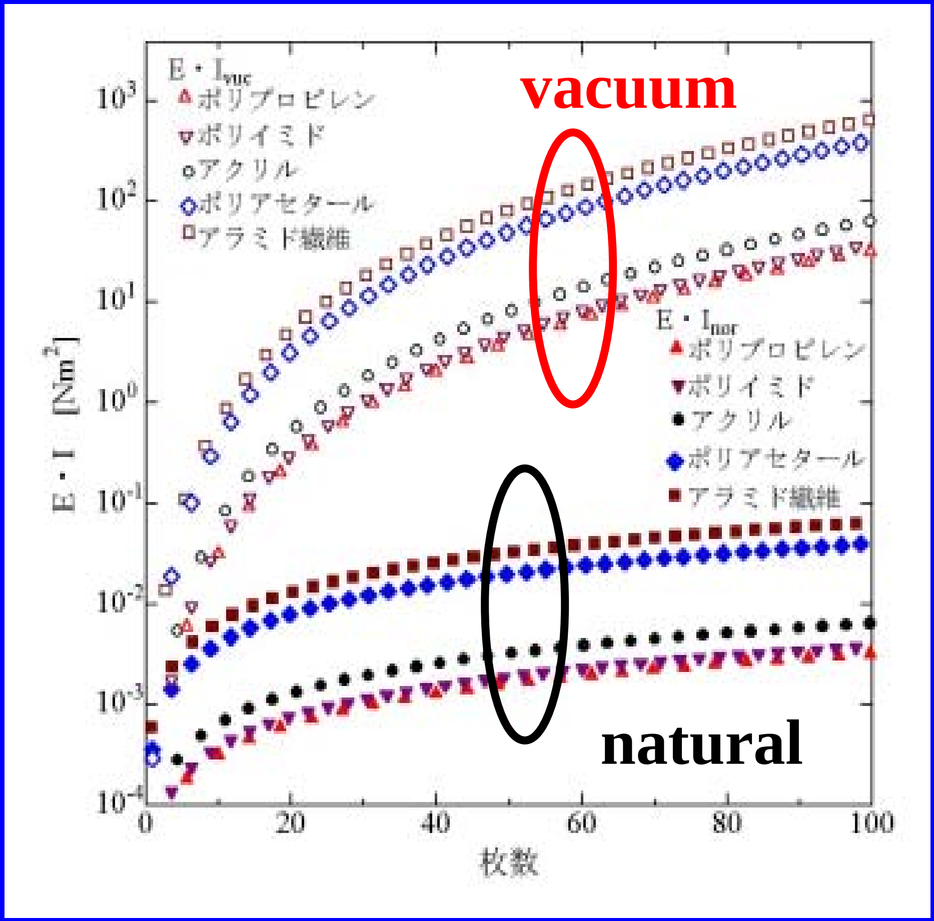
b width

h thickness




beam

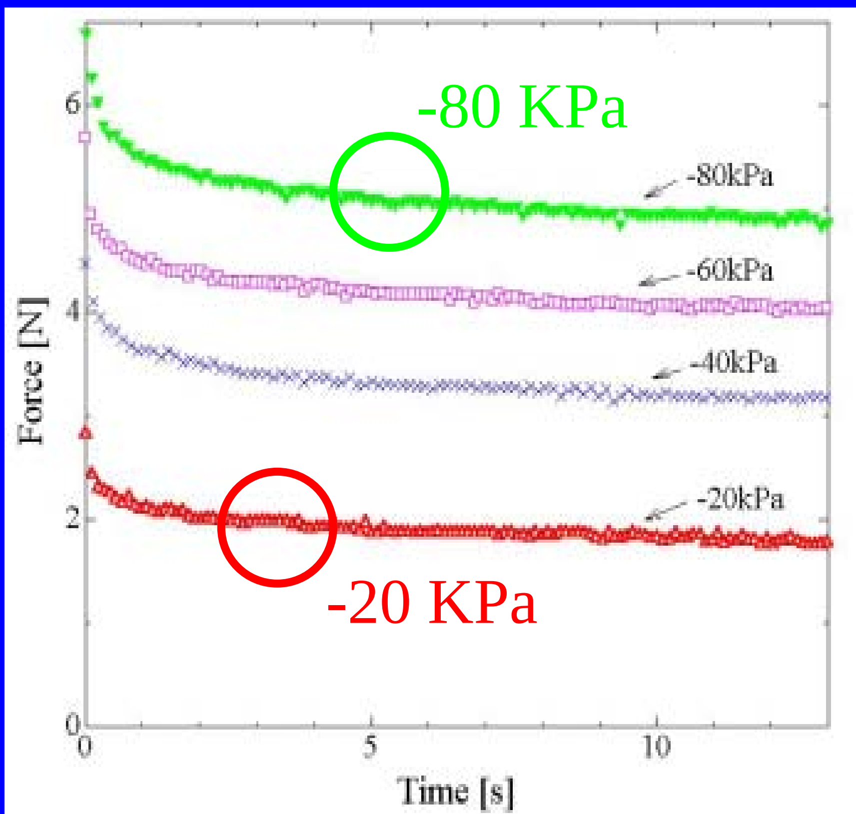
## Bend rigidity



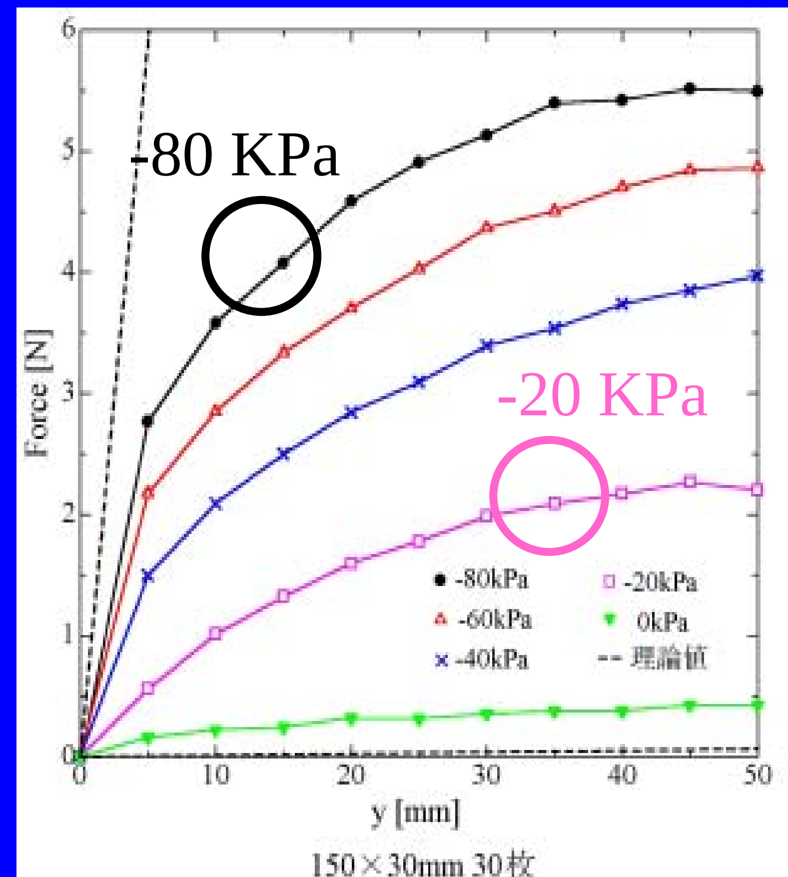

n number of films

# Property of VBR device

## Bending force - Time




## Bending force - Displacement

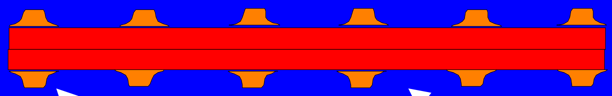


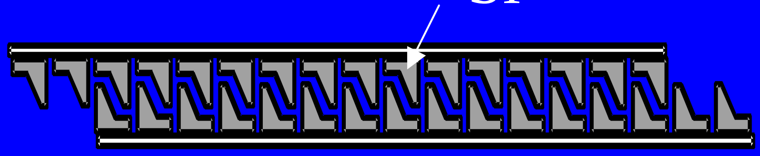

30 Polypropylene films (150mm × 30mm)

# Micro surface machining

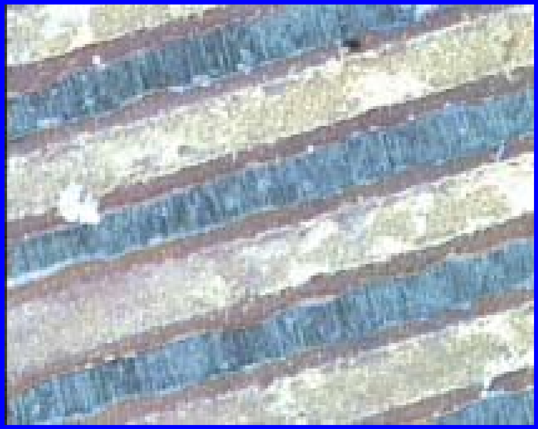
Goal: increase bend rigidity

Solution: micro teeth on films



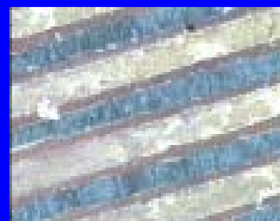

Acrylic acid resin

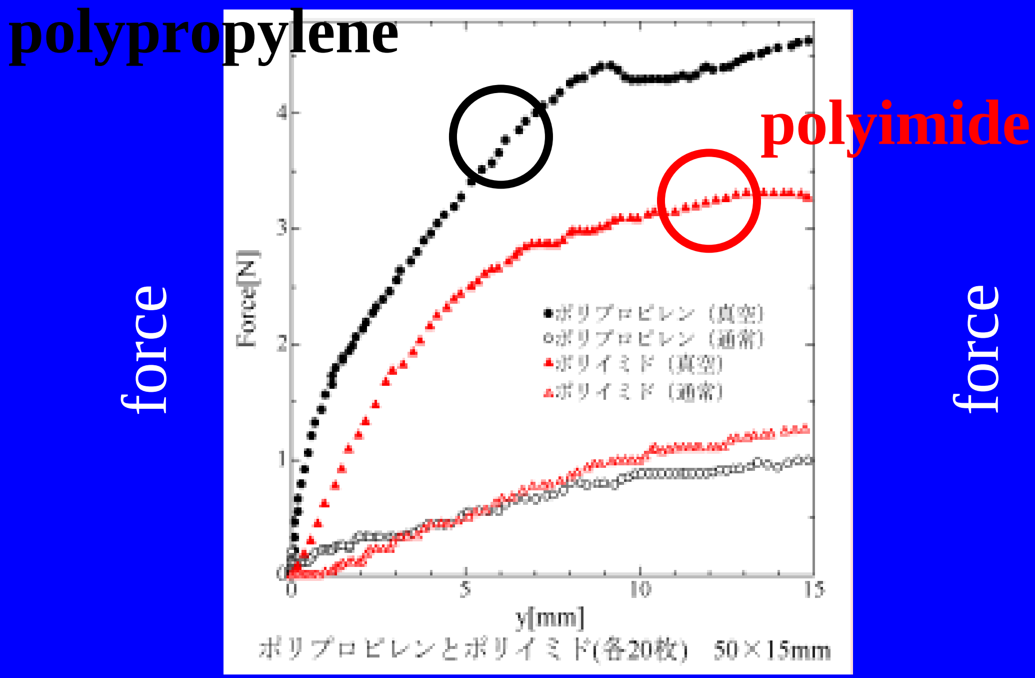


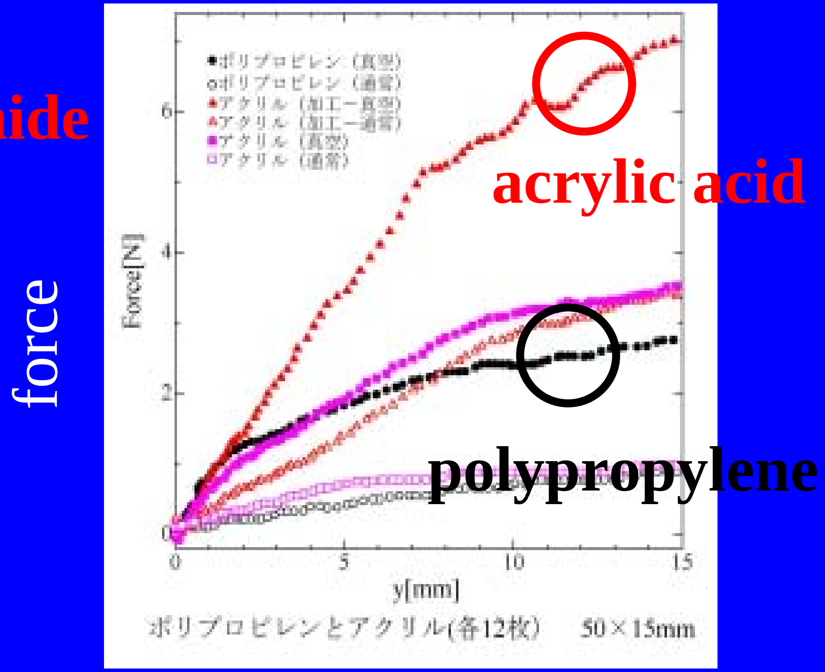
Polyimide (✕200)

Acrylic acid resin (✕200)

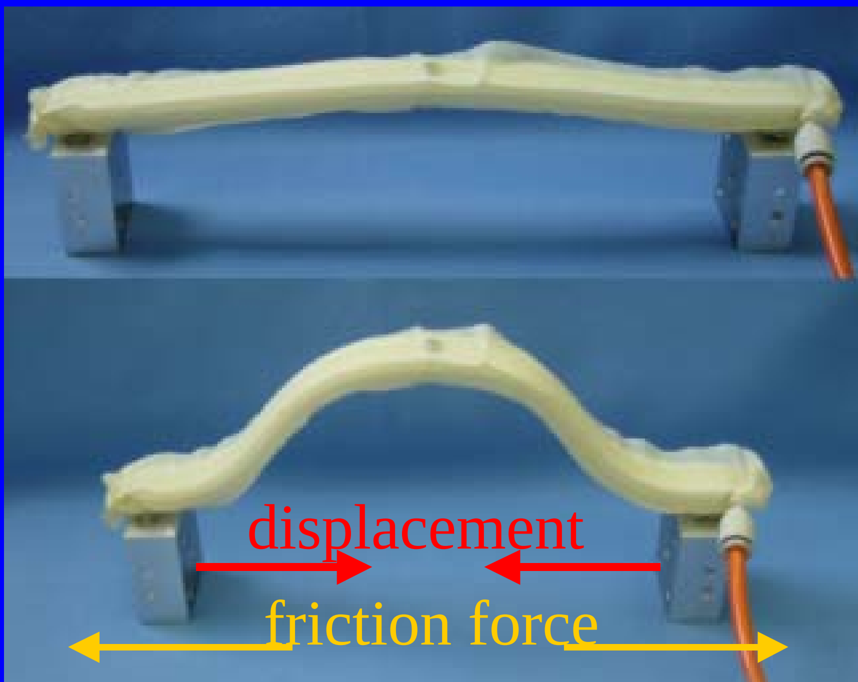
# Measuring bend-rigidity

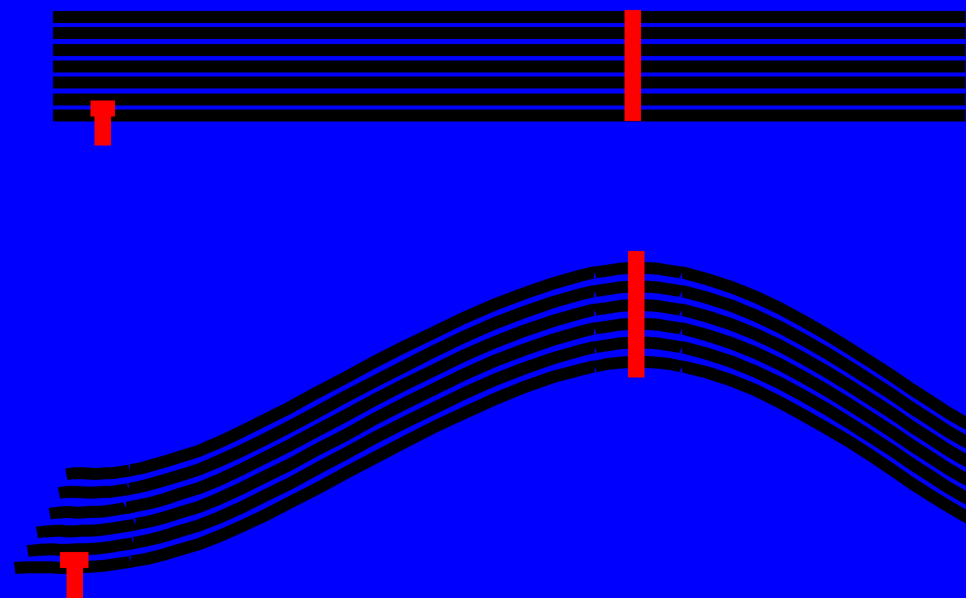




# Variable Viscosity



$$F = B(n, p, s)\,\mathrm{sgn}(\dot{x}) + K_s(x, n, s) + K_c(x, p, s)$$

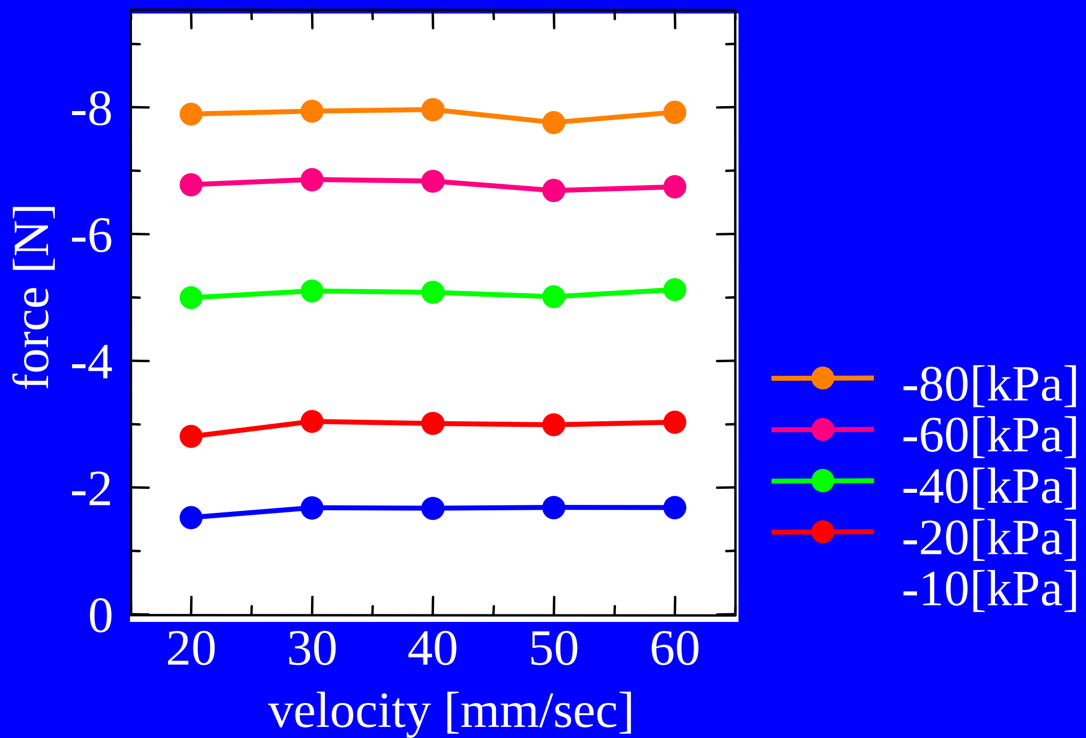
$B$ : friction $K_s$ : Film elasticity $K_c$ : Envelop elasticity

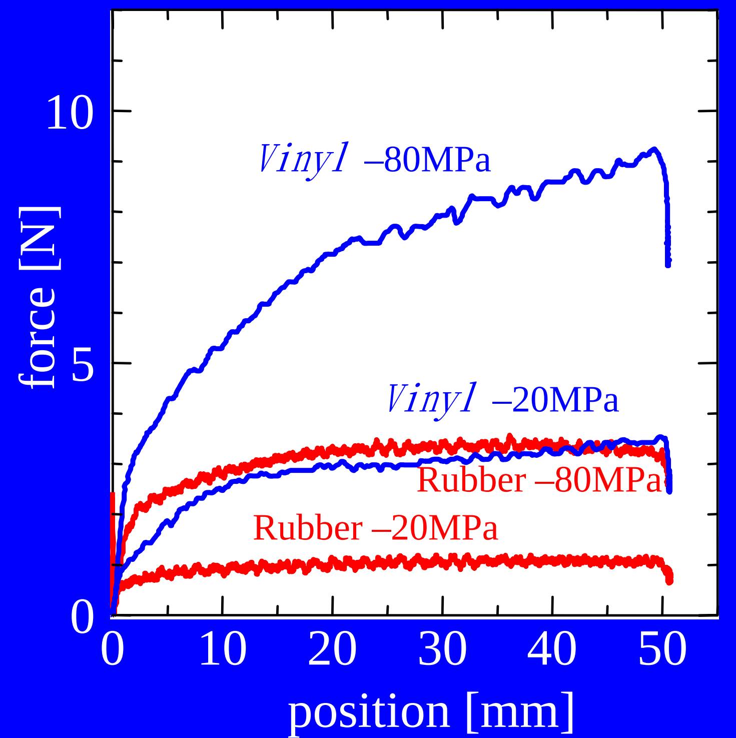
$n$ : # of films $s$ : film area $p$ : pressure $x$ : displacement

# Dynamic Property of VBR device

$$F = \boxed{B(n,p,s)\,\mathrm{sgn}(\dot{x})} + \cancel{K_s(x,n,s) + K_c(x,p,s)}$$

Dominant term: Coulomb friction



# Virtual Viscosity

$$\boxed{F = B(n, p, s)\,\mathrm{sgn}(\dot{x})}$$

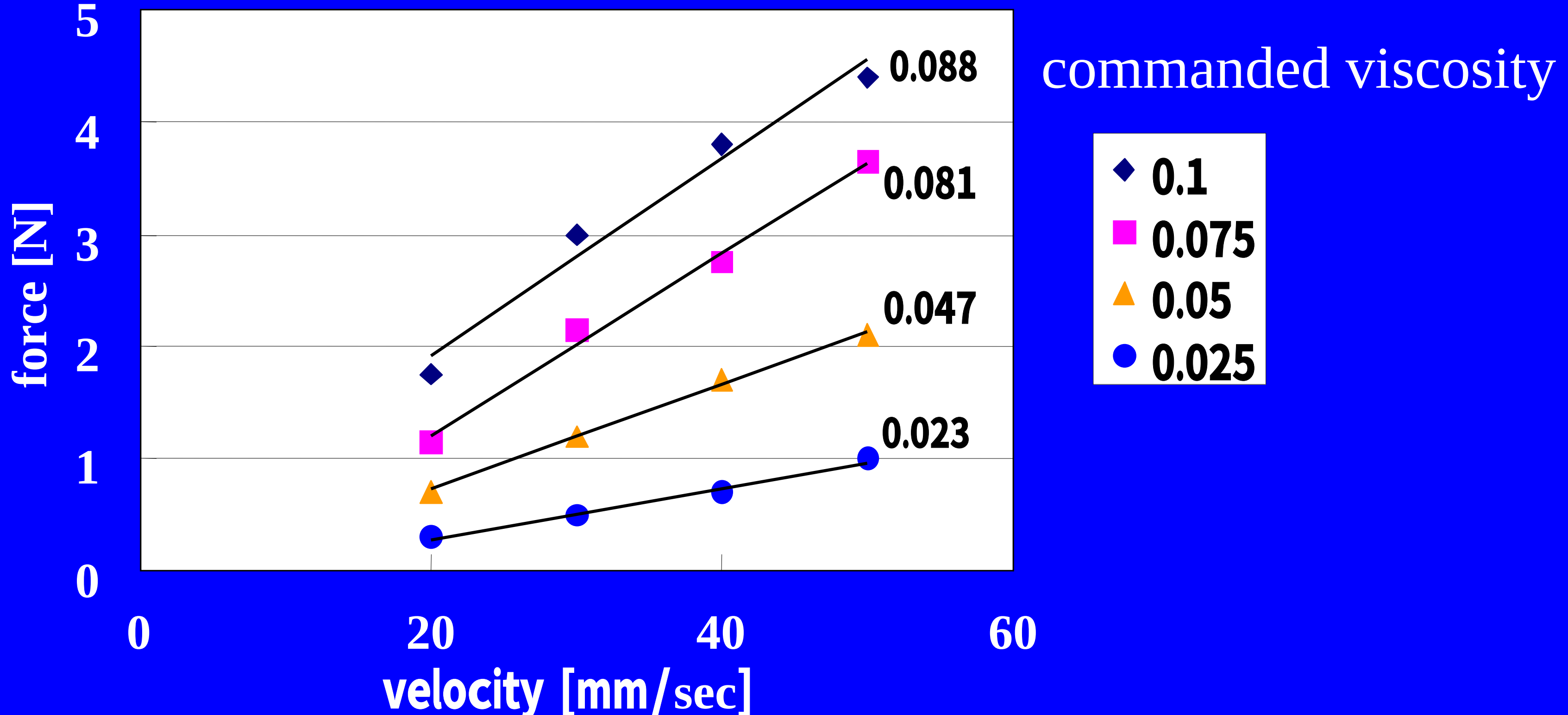
$F$ is proportional to $p$

$$F = B(n, s)\,\mathrm{sgn}(\dot{x})\,p$$

$n, s$ : const

$$F = B(n, s)\,k\,\dot{x}$$

control $p = k|\dot{x}|$

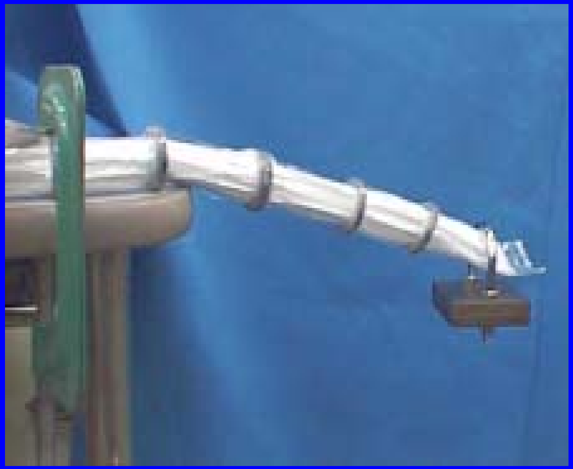


# Linear Variable Bend-rigidity (LVBR)

# Type-E

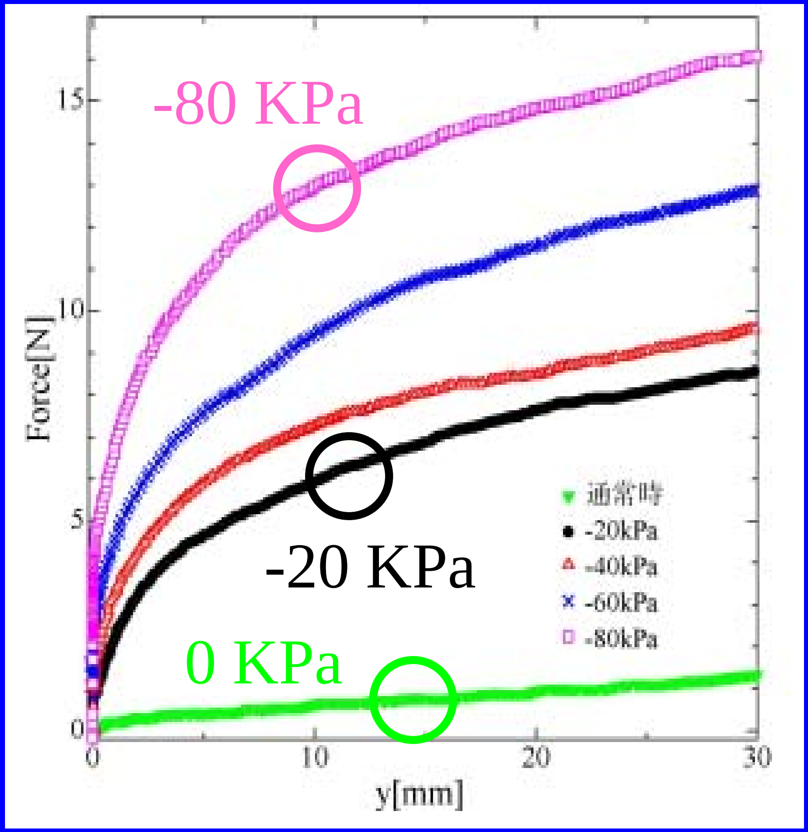
Multiple fibers in an envelop

Natural state



Vacuum state

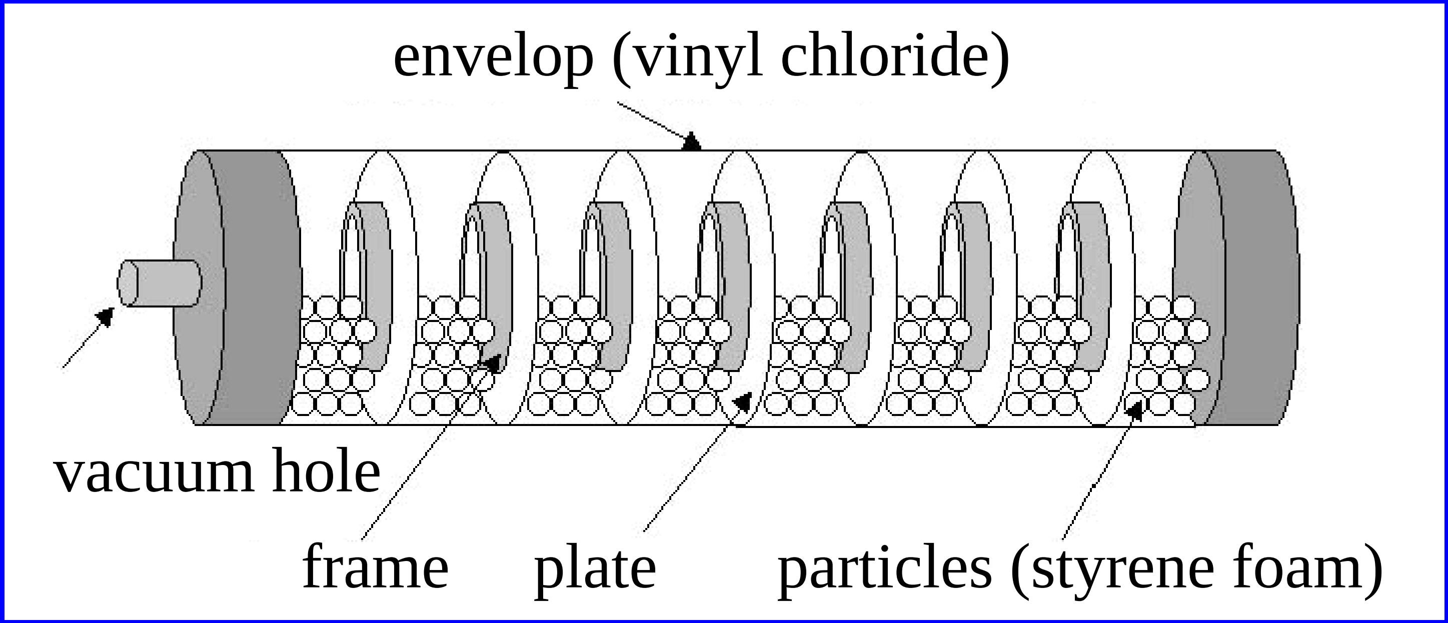
Force-displacement



# Variable Whole Rigidity

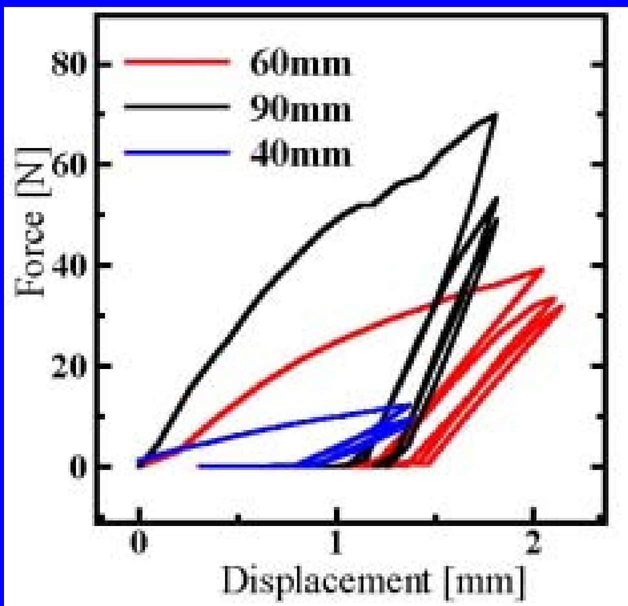
## Type-G

Particles on an envelop
Inside vacuum increases
the rigidity

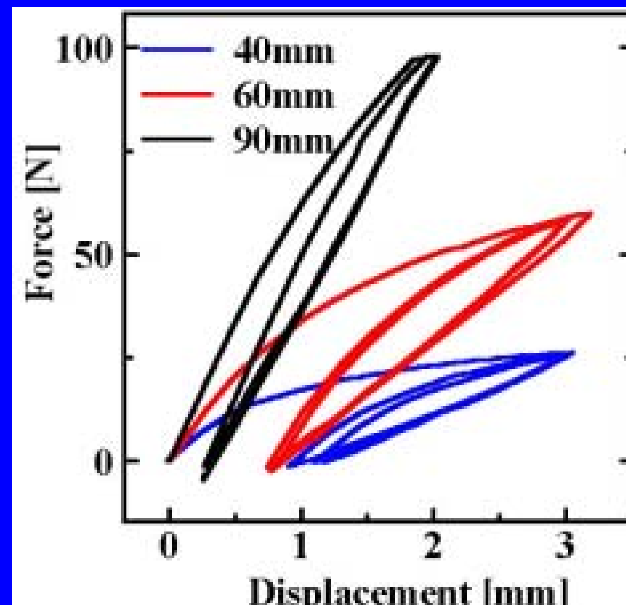


# Property of VWR

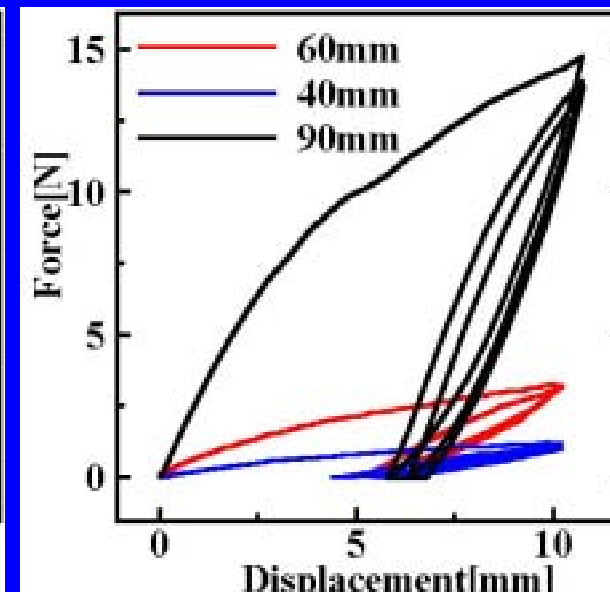
## Expansion




## Contraction




## Bending




Contraction rigidity is proportional to radius

Bend rigidity is proportional to geometrical moment of inertia

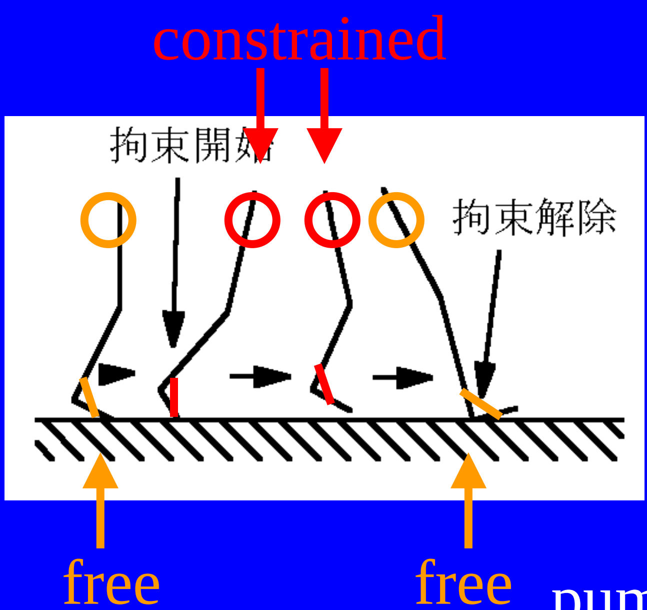
# System Integration

Ankle Orthosis
Orthosis for Stair Descending

Wearable Haptic Device for Hand
Wearable Virtual Reality

Assist of Upper-Limb Motion
Assist of Standing-up Motion
Assist for Jumping

# Ankle Orthosis






Total weight : 770g

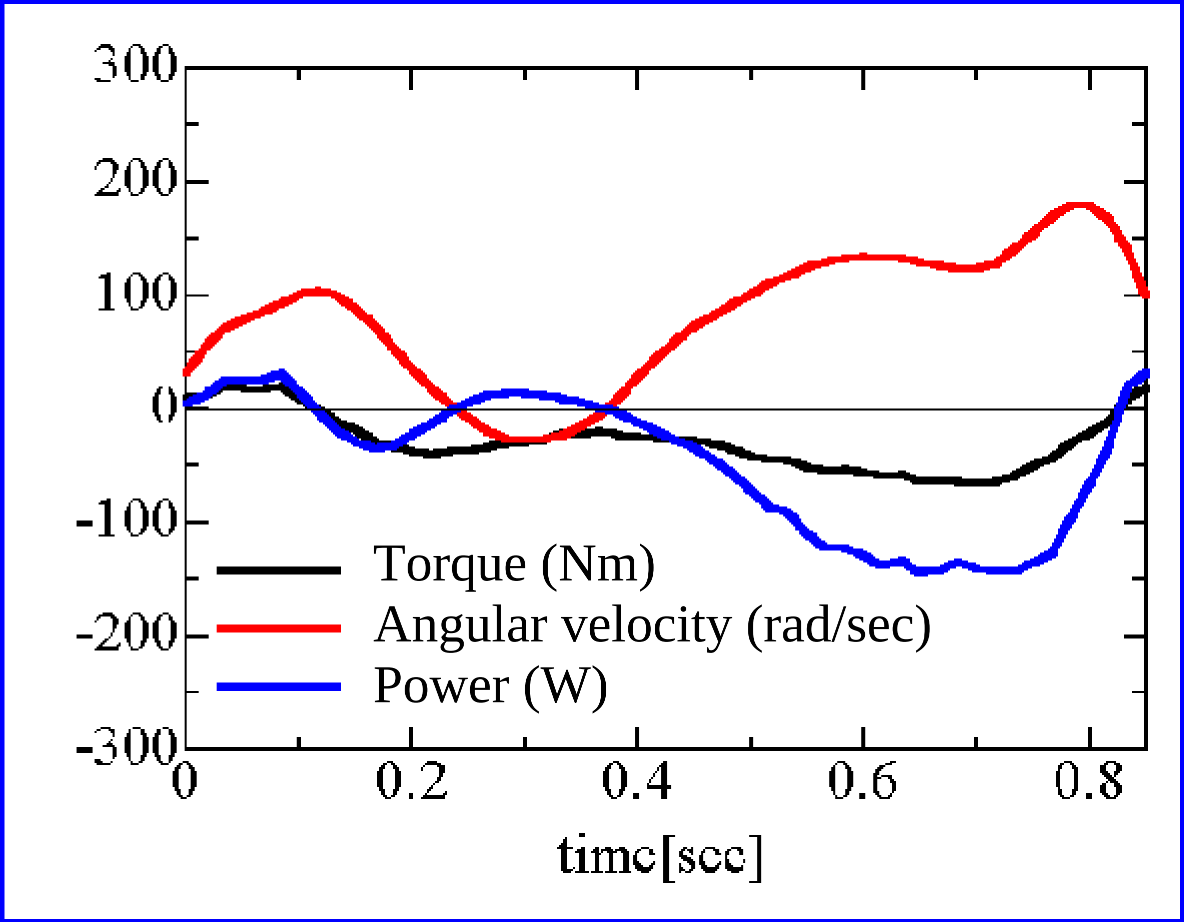
Pump is activated by spring

# Orthosis for Stair Descending

vacuum

70 Polypropylene films (300mm×90mm)

# Motion during descending




# Elbow Orthosis

Two VER devices
Attached to the elbow center
Angle sensor

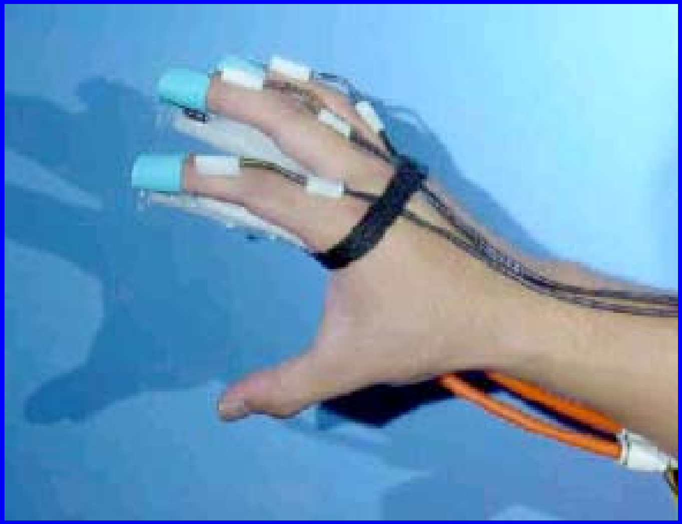
70 Polypropylene films (325mm × 80mm)

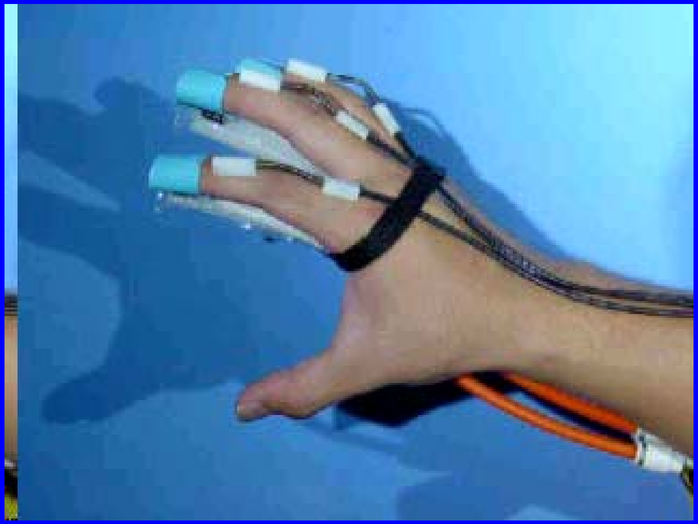
# Wrist Orthosis

Two VER devices
Attached to the wrist center
Angle sensor

20 Polypropylene films (160mm × 50mm)

# Finger Orthosis





Three VWR devices
Attached to the finger base
Sliders at fingertips

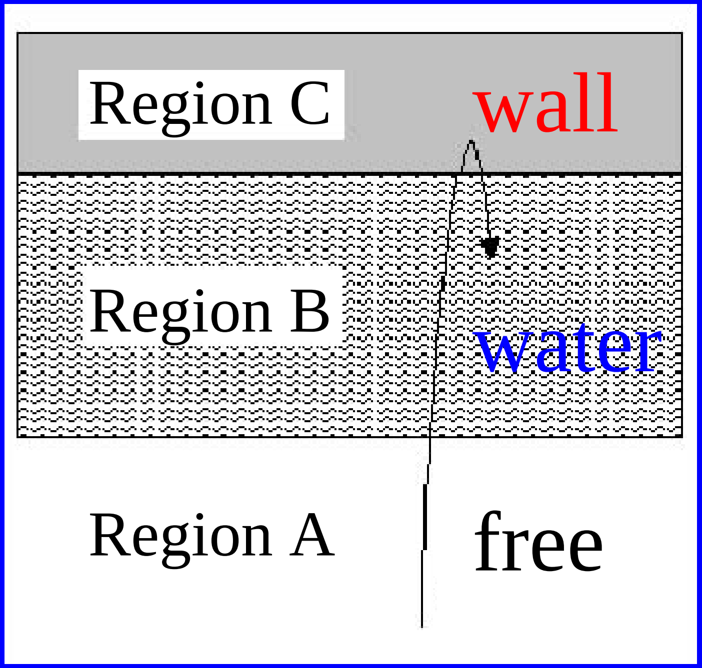
30 Polypropylene films (100mm × 10mm)

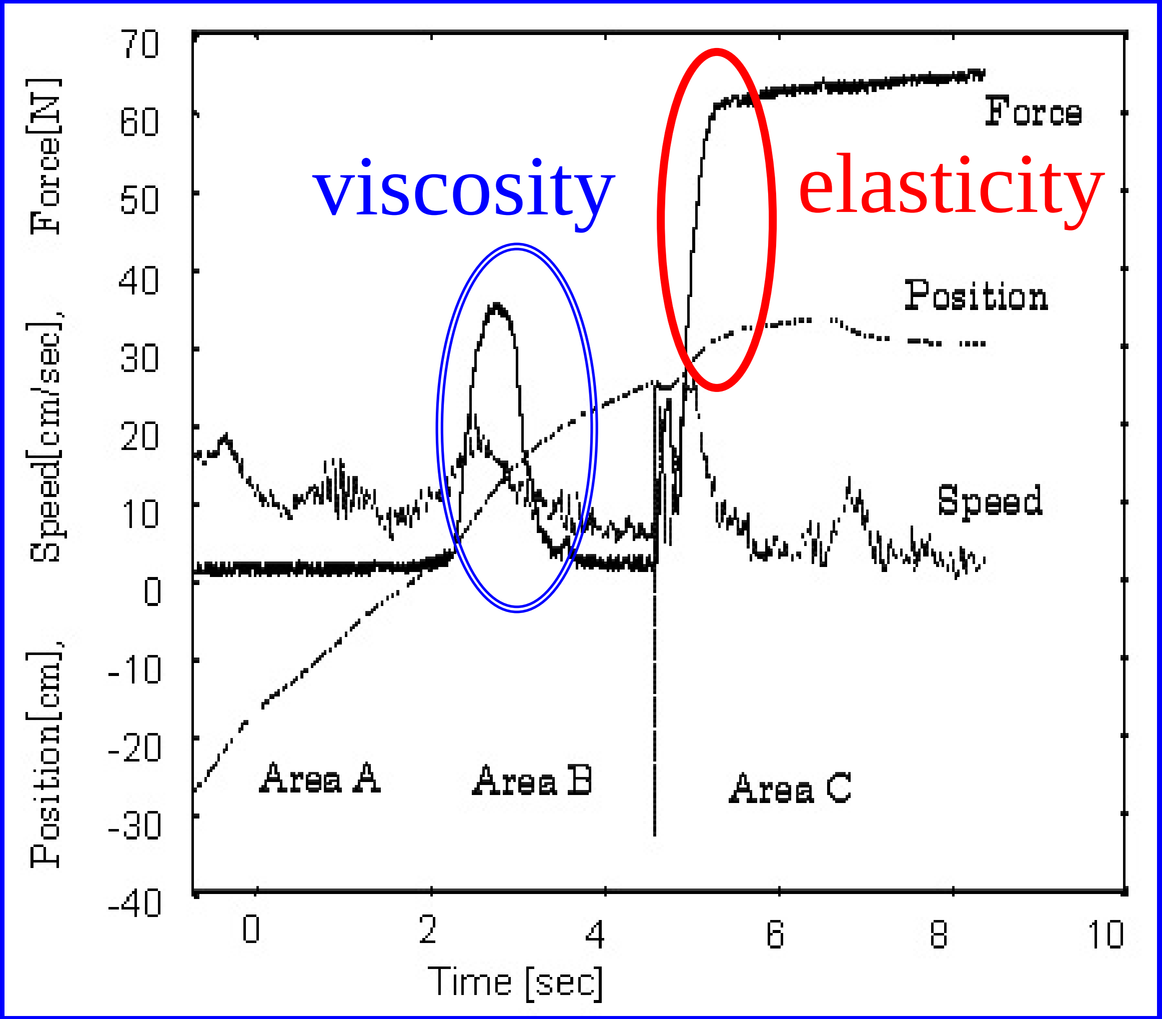
# Wearable Haptic Device for Hand

# Wearable Virtual Reality

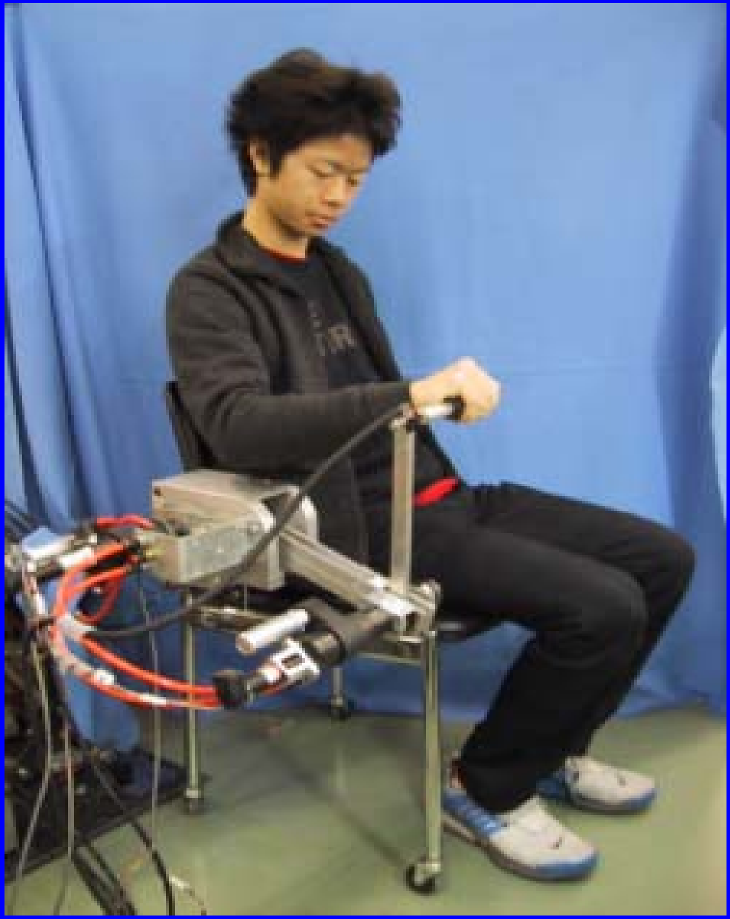
# Virtual Boxing

# Virtual Elasticity and Viscosity

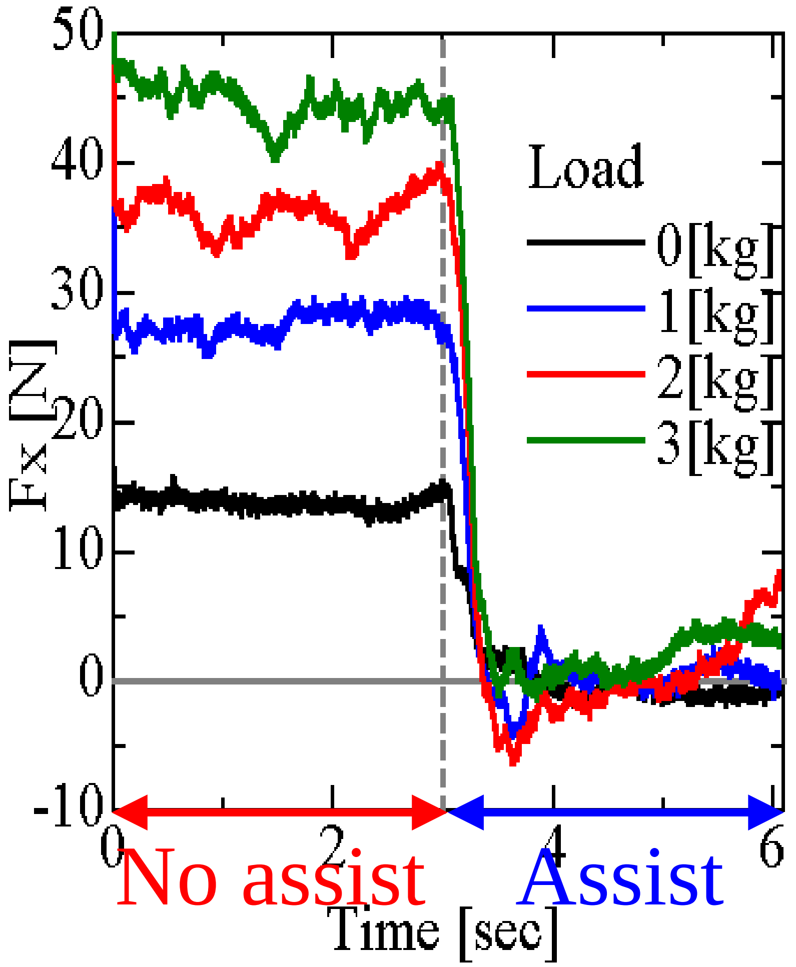


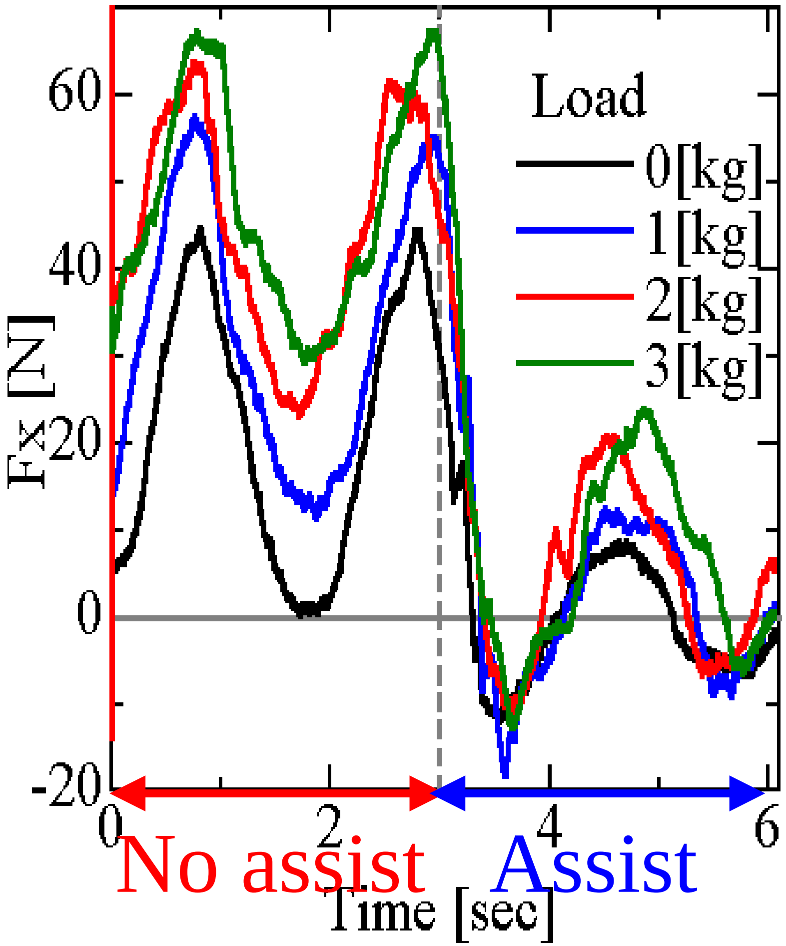



# Assist of Upper-Limb Motion



# Upper-Limb Motion Assist

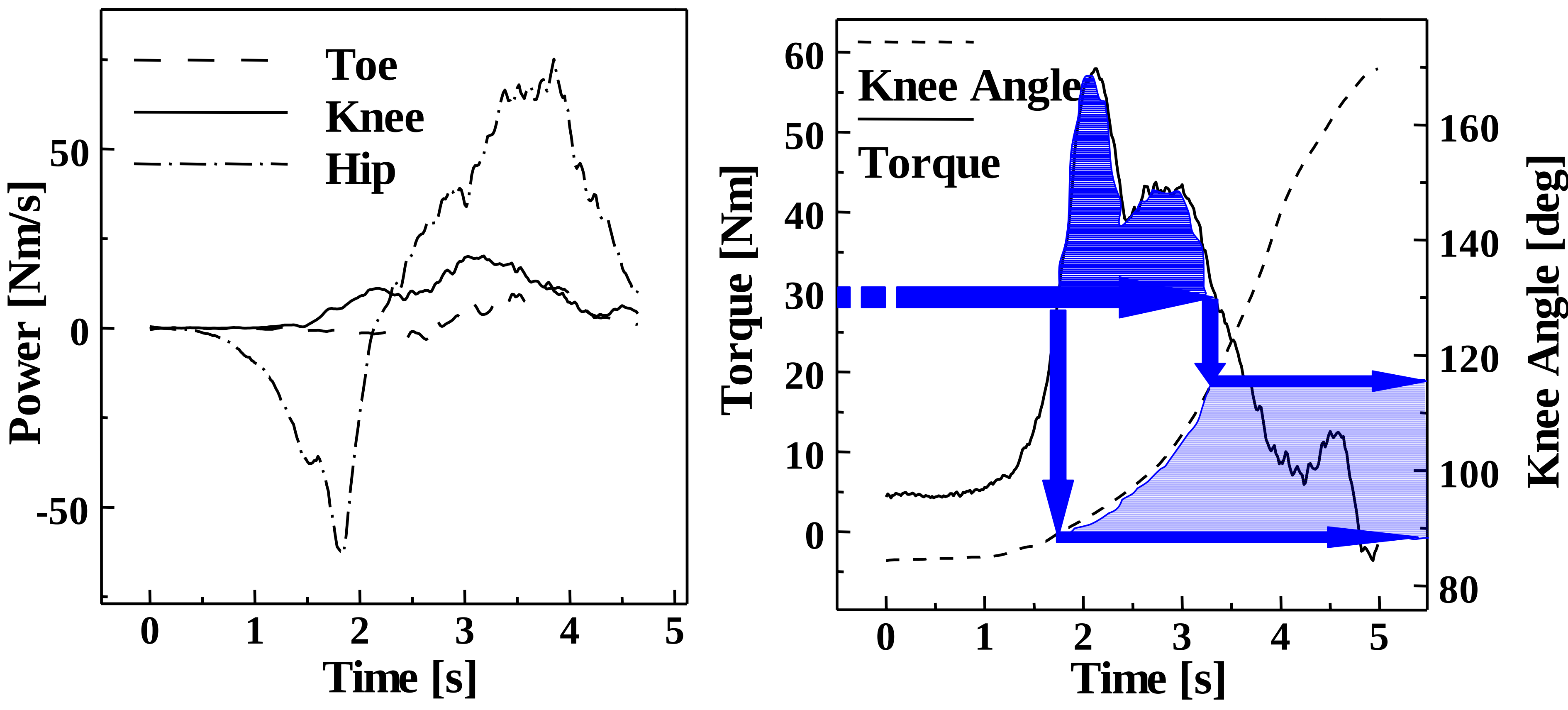


# Assist of Standing-up Motion

Total weight : 2 Kg
Actuators : HRA 220g×2

# Torque during stand-up motion



# Air Supply System

Tank : 293g

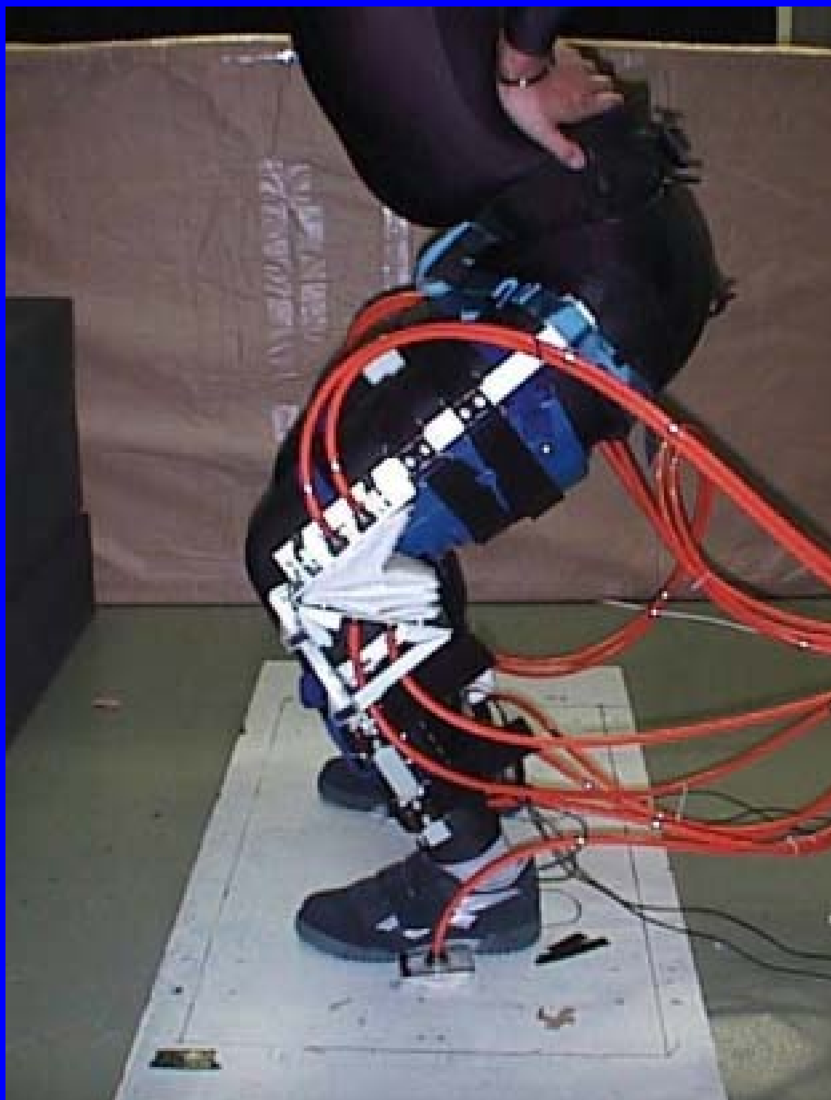
Regulator : 264g

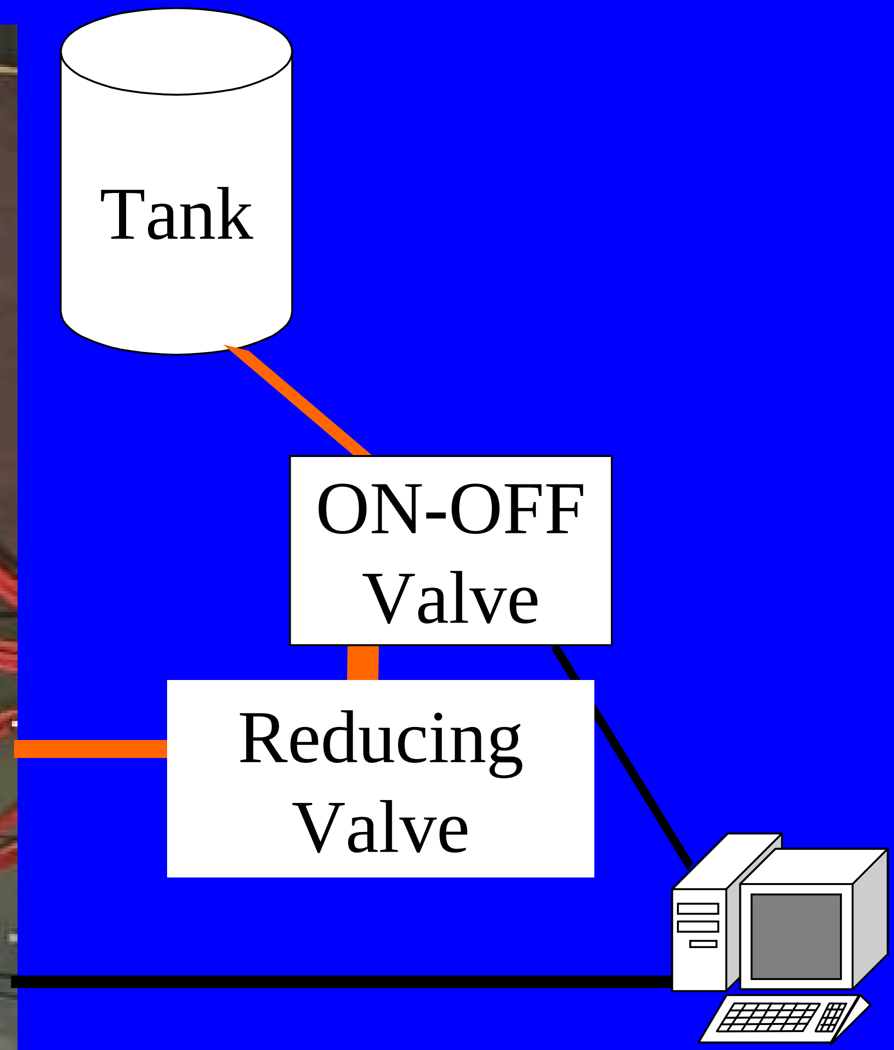
Compressor : 240g

Max pressure : 145 KPa

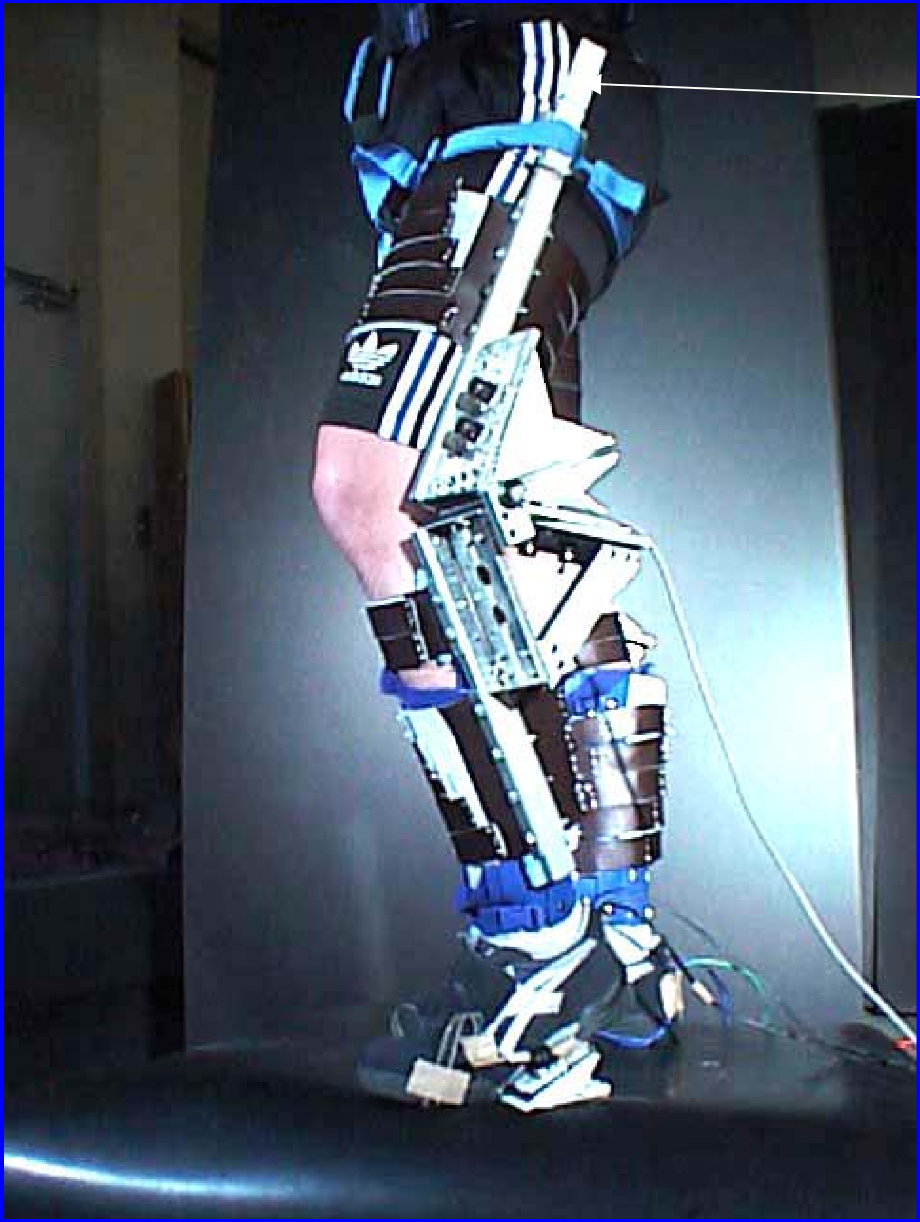
Supply : 73 times (173 KPa) (Human weight 60 Kg)

# Assist for Jumping





# Jump Assist Orthosis



Variable Extensional-rigidity devices

Total weight : 1.65 Kg
Actuators : 200g × 2

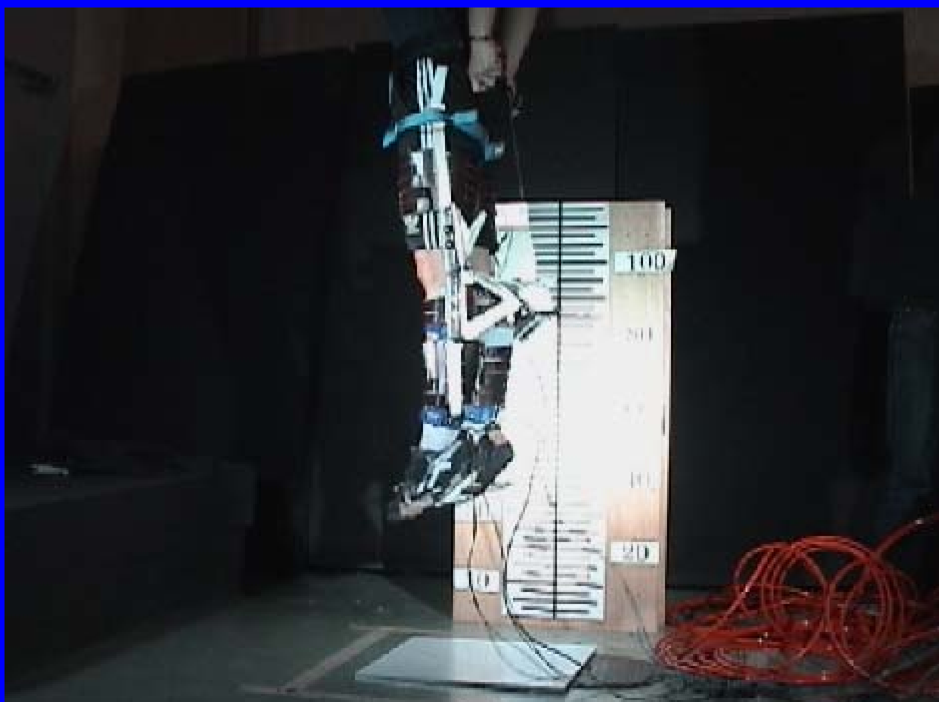
Control delay : 0.05 sec

# Jump Assist Orthosis (Foot)

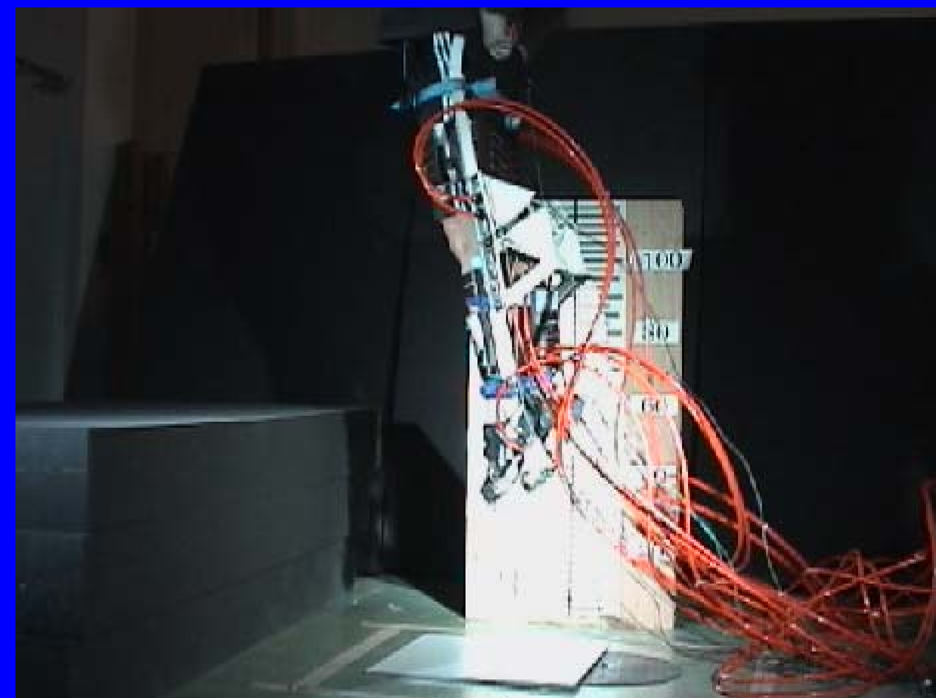
Total weight : 500g
Actuators : HRA
40g × 2

Touch sensor

# Experiment




Without assist




With assist

# Conclusion

- Pneumatic Active/Passive Devices
- Prototyping Devices

  active: PGA, HRA

  passive: VER, VBR, LVBR, VWR
- Control of Passive Devices

  virtual viscosity
- Designing and Prototyping Orthosises

# Ongoing Issues

- Synchronization with Human Motion
- Attaching to Humans
- Miniaturization of Air Distribution System